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New Techniques for Monitoring Drip Irrigation Water Use Efficiency, Drainage, and Leachate in Container Nurseries

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Abstract*. Techniques are needed to ecologically monitor nursery production practices with proper use of water resource and nutrient management. An experimental system to examine water quality, irrigation efficiency and drainage from pot-in-pot nursery container production was established in a commercial nursery field. The system mainly consisted of a plot containing 50 trees planted in 50 pot-in-pot containers and irrigated with micro spray stakes; 10 drainage water measurement devices; 10 pot media moisture probes; 10 thermocouples; a weather station and a data logger. Preliminary tests indicated the system was feasible to monitor water inputs, drainage water loss, medium moisture content and temperature, leachate of nitrogen, phosphate and potassium in drainage water, rainfall and weather conditions, and tree growth in pot-in-pot nursery production.*

Keywords. *Environment, Irrigation, Medium, Moisture, Ornamentals, Plant Growth, Rainfall, Temperature.*

Introduction

Water will be one of the most challenge resources in the world in next 20 years. Efficient use and availability of a quality water source has been a major concern in the nursery industry for many years (Yeager, 1992; Irmak, et al., 2003). Without scientific guidelines to properly apply water, nursery crop production will be limited in places and species in the future. Due to lack of scientific methodologies to guide irrigation practices in nursery industry, growers usually apply water to the crops by simply turning on valves without knowing how much water loss through runoff and drainage. Overhead sprinkler systems are widely used to irrigate container-grown nursery crops, but during the growing season over 80% of the water is lost through runoff, drainage and evaporation (Weatherspoon and Harrell, 1980).

Nursery growers are using a new method, the pot-in-pot system, to produce higher quality crops at reduced labor costs. This production system has been expanding rapidly during the past decade. The system can moderate root temperature and improve root quality, prevent the blowing over of container-grown trees, and reduce harvesting labor cost. However, with this production technique, it is essential to apply sufficient water two or more times throughout a day and supplemental nutrients to sustain the rapid growth of trees (Beeson and Gilman, 1995; Ruter, 1997). These irrigation and fertilization practices have raised concerns over water use efficiency and the extent of nutrient leaching with the drainage water to the soil and ground water (Yeager et al., 1993; Fare, et al., 1994). Also, improving irrigation management is limited because drainage water loss through the in-ground containers cannot be directly observed.

The amount of drainage water loss from a container due to irrigation is relatively low, but the amount could be considerably higher due to intensive rainfall. Compared with the conditions in fields, the pot-in-pot system requires complex production practices due to the various types of medium, species and irrigation schedules. Small rain gage tipping buckets showed to be a suitable method for this application (Zhu et al., 2004). Large tipping buckets have been widely used to measure surface water runoff and subsurface drainage in farm fields for many years (Bentz and Amerman, 1968; Barfield and Hirschi, 1986; Hanna, 1995; Zhao et al., 2001).

For the above ground container production, considerable research has been done on the interactions among water quality, water use efficiency, nursery crop growth and production practices in applications of required amounts of fertilizer and pesticides to crops with minimum nutrition and chemical loss. However, for pot-in-pot nursery production, very little research has been done on problems associated with water runoff, drainage and potential of chemical leaching in nurseries. Knowledge is shortage on the integration in water and nutrients for a plant to have optimal growth. Techniques are needed to ecologically monitor nursery production practices with proper use of water resource and nutrient management. To fully explore potential impacts of the pot-in-pot production system on nursery production, knowledge of water quality and quantity to produce healthy trees is needed to improve application efficiency and reduce the potential of soil and groundwater contamination.

The objective of this research was to develop a pot-in-pot production monitoring system to examine total amounts of irrigation, rainfall and drainage water loss from the pot-in-pot nursery production, nutrition leachate level, tree growth, time to start and stop drainage after irrigation or rainfall, medium moisture content, medium temperature, precipitation, and other weather conditions.

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Materials and Methods

An experimental system (fig. 1) to examine water quality, irrigation efficiency and drainage from pot-in-pot nursery container production was established in a commercial nursery field. The system mainly consisted of a plot containing 50 trees planted in 50 pot-in-pot containers and irrigated with micro spray stakes; 10 drainage water measurement devices; 10 pot media moisture probes; 10 thermocouples; a weather station and a data logger. After the system was established at the end of July, 2003, data were collected on the amount of irrigation, drainage water loss, medium moisture content, medium temperature, weather conditions, and tree caliper at 18 cm above the soil surface. The leaching level of nitrogen (N), phosphate (P), and potassium (K) in water drainage were analyzed weekly from water samples. The detailed description of the system development was given below.

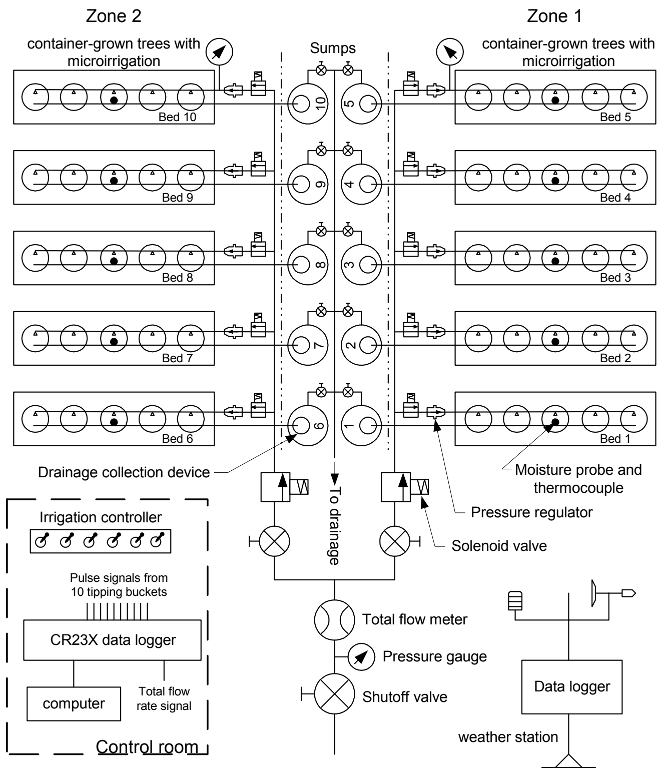

Figure 1. An experimental field plot containing 50 pot-in-pot production trees to examine water input, drainage water loss, leachate of nitrogen, phosphate and potassium in drainage water, medium moisture content and temperature under various weather conditions in four seasons of a year.

Experimental plot design

Two adjacent zones were selected to install 50 pot-in-pot containers with trees. Each zone had five beds, and each bed had five pot-in-pot container-grown trees. Spacing between the beds was 1 m, and spacing between the trees was 1.5 m. Each tree container had a volume of 58 L and 43.2 cm in diameter, and was placed inside a socket container. The socket container was installed in the ground to the lip of the container (fig. 2). The potting medium was composed of 55% pine bark, 3% sand, 5% Haydite soil conditioner, 20% sterilized regrind potting soil, 12% peat, and 5% composted municipal sludge. Red Sunset maple (*Acer rubrum 'Franksred'*) trees were selected for the test because of the popularity in nursery production. The caliper of each tree at 18 cm above the ground was measured once a week. The average tree caliper was 1.4 cm when they were transplanted in the pot-in-pot system on July 3, 2003.

The container-grown tree was irrigated with a spray stake (Netafim USA, Fresno, CA) inserted vertically near the container side wall to ensure all applied water was evenly spread out within the container. Each bed had an irrigation supplying line with a 70 kPa pressure regulator to minimize variations in application rate. A solenoid valve was installed before the regulator at the beginning of the irrigation line to control irrigation schedule for each bed. A manual gate valve and a solenoid valve were installed in the water supply line to each zone. A Model 1200 inline vortex flow rate meter (Fluidyne, Longmont, Co) was used to measure total flow rate and total amount of water applied to trees in two zones. Irrigation management was controlled with micro-switches in a control room (fig. 1).

Production practice

The system started in use on August 6, 2003. Irrigation was applied twice a day until November 16 under the conditions that there was no sufficient rainfall to wet the potting medium before water was applied. Spray stakes with two different sizes (11.6 and 27.1 L/hr, respectively) at 70 psi were used to verify the accuracy of the rain gage units to measure amount of drainage from container-grown trees, and irrigation rate was controlled for five separate weeks during the growing season (Zhu. et al., 2004). Except for the five separate weeks, the irrigation application rate during the rest of the growing season was managed following the production practice in an 18.2 ha commercial pot-in-pot production area adjacent to the experimental system. Between August 6 and November 16, 2003, a total of 19.3 cm irrigation was applied to the trees, and total precipitation received was 598 mm (fig. 3).

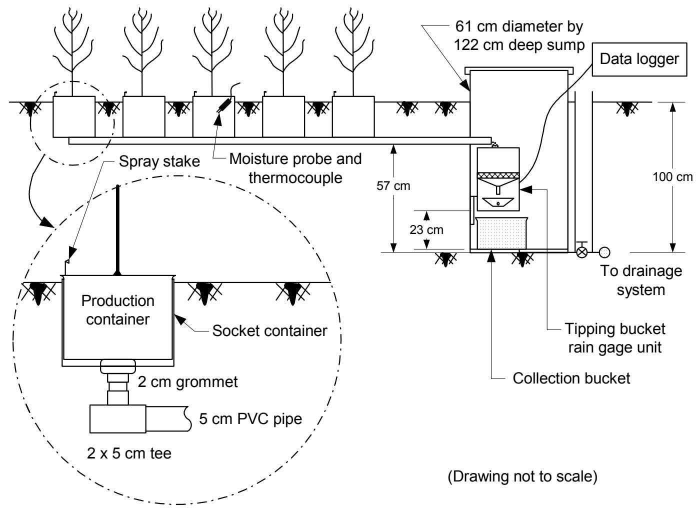

Figure 2. Diagram of drainage water loss measurement from 5 pot-in-pot tree containers in a bed.

Slow release granular Scott's 20-5-8 fertilizer was applied to trees when the trees were transplanted in the containers. The fertilizer was applied at the rate of 119 grams per tree, and 28% nitrogen was injected into irrigation at 200 ppm at every 19-day watering cycle.

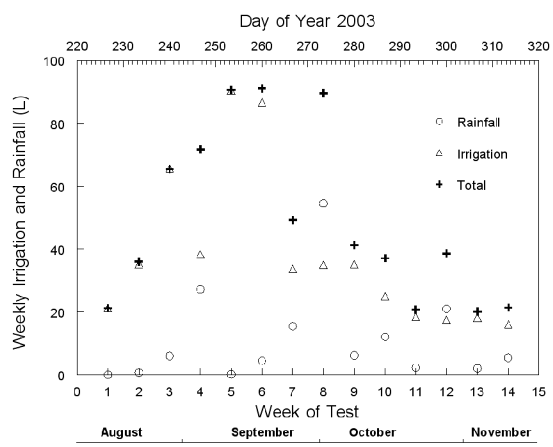

Figure 3. Weekly rainfall and drip irrigation applied to 5 pot-in-pot production trees in a bed between August 6 and November 16, 2003.

Drainage water loss measurement

A Model 3665R electronic "tipping bucket" rain gage unit (Spectrum Technologies, Plainfield, IL) was installed 0.43 m below the soil surface in a 0.6 m diameter and 1.2 m deep sump (fig. 2) to measure water drainage from five tree containers in each bed. A total of 10 rain gage units were used for 50 container-grown trees in 10 beds. A 5 cm (2-inch) PVC pipe was installed 7 cm under five containers in each bed to guide drainage water to the rain gage unit. Detailed information on the drainage measurement in this system was given by Zhu et al. (2004). The rain gage units were removed from the system and stored under room condition during winter to prevent winder damage.

Water quality analysis

A water sample from five tree containers in each bed was collected every week for water quality (N, P, K, and pH) analysis. The samples were stored in a refrigerator after they were brought from the field before analysis. The content level of N (No_3-N) in each sample was detected with a Model DX120 liquid Ion chromatography analyzer (Dionex Corporation, Strongville, OH), and the content level of P and K were detected with a Model PS2000 Simultaneous ICP analyzer (Leeman Labs, Inc., Lowell, MA). The pH level of water samples were measured with a Model MA235 pH/Ion analyzer (Mettler-Toledo GmbH, Schwerzenbach, Switzerland) under the laboratory conditions. In 2003, drainage water from the plot was collected until November 16 when irrigation was no longer applied for the growing season.

Soil moisture and temperature measurement

The potting medium moisture was measured with ten ML2X Theta probes (Delta-T Devices Ltd, Cambridge, England). Each bed had one probe installed 5 cm below the potting medium surface in the middle container. The probes were placed 45° in the potting medium and 5 cm from trees. The probes were calibrated with the potting medium with water containing 200 ppm of nitrogen at the moisture content ranging from 5 to 55%. Water was saturated in the medium at the moisture content between 52 and 56%. The medium temperature at 5 cm below the surface in the middle container in each bed was measured by 10 thermocouples (Thermo Electric Co., Inc., Saddle Brook, NJ) with galvanic effect prevention. The thermocouple was installed beside the moisture probe.

Weather station

A moveable weather station equipped with a CM-6 system (Campbell Scientific, Inc., Logan, Utah) was installed near the experimental plot to measure precipitation, air temperature, relative humidity, solar radiation, atmospheric pressure, and wind speed and azimuth. The data were collected every 15 minutes and were transferred to a network website for analysis.

Data acquisition

A CR23X data logger (Campbell Scientific, Inc., Logan, Utah) was used to process and acquire data from 10 rain gage units for drainage water measurement, 10 potting medium moisture probes, 10 thermocouples and the total input flow rate meter. The data logger was connected with two synchronous communication modules to allow multi-signal inputs simultaneously. The system acquired data from rain gage units, moisture probes and thermocouples at the interval of once a minute during the growing season. In winter, medium moisture and temperature were collected once a 30-minute while drainage was not measured because of freezing. The total irrigation flow rate was collected each second only during the irrigation period.

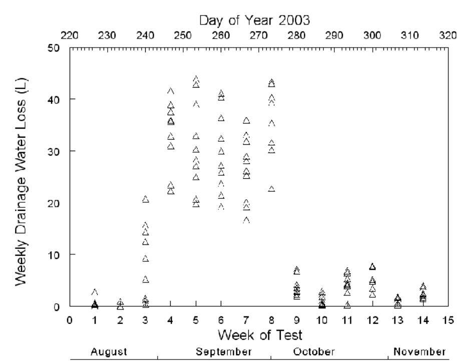

Figure 4. Weekly drainage water loss from 5 pot-in-pot containers in a bed between August 6 and November 16, 2003.

Results and Discussion

Amount of drainage loss

Data shown in Figure 4 are the amount of drainage water collected from 50 containers on 10 beds because of irrigation and rainfall between August 6 and November 16 in 2003. During the 14 weeks of test, total amount of water drainage loss from 50 containers was 1900 L while total water and rainfall to the 50 tree containers was 6,940 L. About 27.4% of water and rainfall lost though drainage. Most drainage loss occurred between week 4 and week 8 due to large amount of irrigation was applied to the trees.

Tests also found that the time when drainage started after irrigation varied with irrigation application rate (Zhu, et al., 2004). The average drainage start time from the 10 beds was 22.3 minutes after irrigation started with11.6 L/hr flow rate for three minutes, and was 7.6 minutes with 27.1 L/hr flow rate for three minutes.

N, P and K leachate and drainage water pH

Figures 5, 6, and 7 illustrate the amount of N, P, and K leachate through drainage water from 10 beds between August 6 and November 16 in 2003. The amount of N, P and K varied with beds.

The system detected that the total amount of N, P and K loss through drainage from 50 containers during 14 weeks was 142.8, 7.2 and 97.8 grams, respectively. Most nutrition loss occurred between week 4 and week 8. After week 9, the amount of N, P, and K leachate decreased considerably because it was close to the end of growing season and the existence level of N, P, and K in the potting medium might be very low.

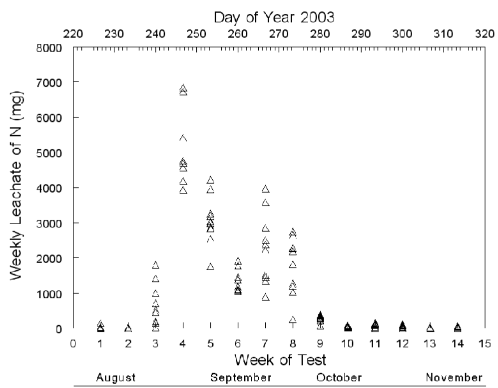

Figure 5. Weekly leachate of nitrate (N) in drainage water from 5 pot-in-pot containers in a bed between August 6 and November 16, 2003.

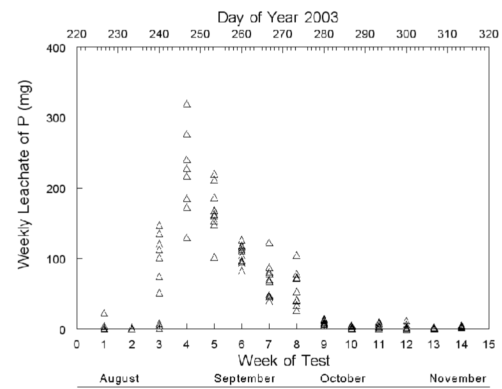

Figure 6. Weekly leachate of phosphate (P) in drainage water from 5 pot-in-pot containers in a bed between August 6 and November 16, 2003.

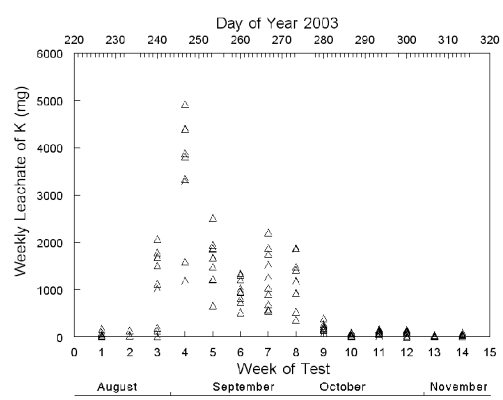

Figure 7. Weekly leachate of potassium (K) in drainage water from 5 pot-in-pot containers in a bed between August 6 and November 16, 2003.

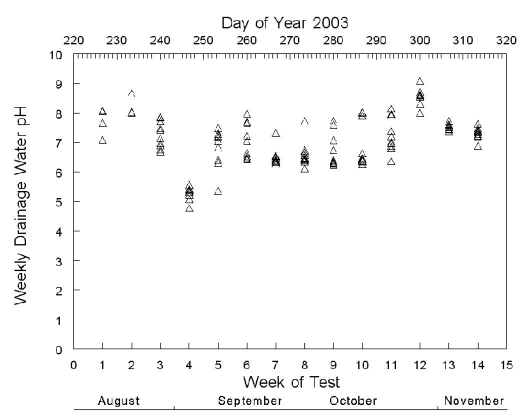

Figure 8. Weekly drainage water pH from 5 pot-in-pot containers in a bed between August 6 and November 16, 2003.

Figure 8 shows the pH of drainage water samples from 10 beds between August 6 and November 16, 2003. The pH stayed within the range from 6 and 8 most time for all 10-bed samples except for week 4 and 12. Unexpectedly, the average pH in week 4 was 5.3 and the average pH in week 12 was 8.6.

<u>Medium moisture content</u>

The medium moisture content varied with beds although the amount of irrigation water and rainfall to all beds were the same. Figure 9 shows the response of medium moisture content in beds 1, 3, 7, and 10 to 27.1 L/hr of irrigation applied for 3 minutes, twice a day, on September 9 and 10. The moisture content reached the saturated point at about 55% in a very short time and then decreased to about 40% within 2 hours after irrigation stopped. Figure 10 shows the response of medium moisture content in beds 1, 3, 7, and 10 to 19.8 mm and 29.0 mm of rainfall reached the area within 30 hours. The moisture content varied with the amount of rainfall and duration. Longer intensive rainfall caused medium stayed at longer saturated situation. The moisture contents for other beds had the response to irrigation and rainfall similar to the beds 1, 3, 7, and 10, but they were not shown in figures 9 and 10 because of the database limitation of the computer program.

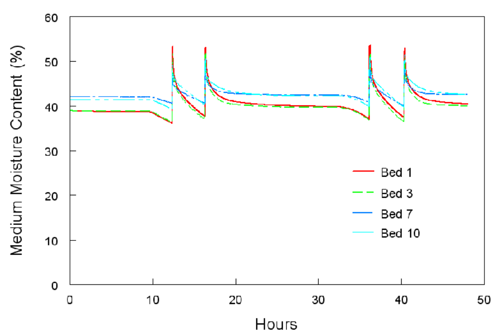

Figure 9. Response of medium moisture content in beds 1, 3, 7, and 10 to 27.1 L/hr of irrigation applied for 3 minutes, twice a day on September 9 and 10, 2003.

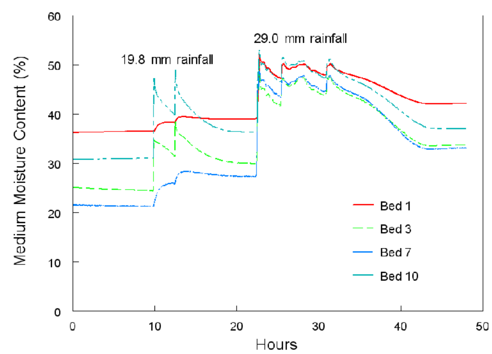

Figure 10. Response of medium moisture content in beds 1, 3, 7, and 10 to 19.8 mm and 29.0 mm of rainfall reached the area within 30 hours.

The daily mean medium moisture content had considerably high fluctuations during summer, autumn, and winter, and had the largest variation in January and February (fig. 11). The medium moisture content at the end of November and whole December was higher than that in September and October. In late November, entire December and early January, due to rainfall and snowfall, the top medium was covered with ice which might protect the moisture near probe sensing area in the root zone from evaporation or drainage. The moisture content at most time in January and February declined below 20% because the probe sensing area was frozen. However, in later February, due to the high

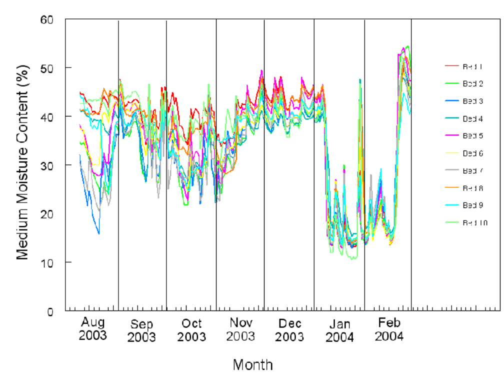

Figure 11. Medium moisture content in the experimental plot measured from August 6, 2003 to February 29, 2004.

ambient temperature, the ice at the top of medium was melted, and the moisture content arose above 40%.

Medium temperature

Figure 12 and 13 shows the medium temperature in bed 1, 3, 5, 7, 9, the daily maximum ambient temperature and minimum ambient temperature in September, 2003 and February, 2004, respectively. Because of data file exceeded the program limitation, the medium temperatures in bed 2, 4, 6, 8 and 10 was not included in figures 9 and 10, but they had trends similar to the temperatures for other beds shown in the figures. In the whole month of September, the medium temperature in 10 beds ranged from 11.7 to 25.4°C while the ambient temperature ranged from 5.1 to 28.9 °C. Relatively, in the whole month of February, the medium temperature in 10 beds ranged from -4.4 to 0.4°C while the ambient temperature ranged from -19.7 to 15.7 °C. Figure 14 shows the average daily medium temperature in 10 beds and maximum and minimum daily ambient temperature between August 2003 and February 2004. The medium temperature in the pot-in-pot system had much lower variation than the ambient temperature within a day, and was independent from moisture levels before the medium was frozen. Contrasting to the medium moisture content, the medium temperature did not have much variation between different beds.

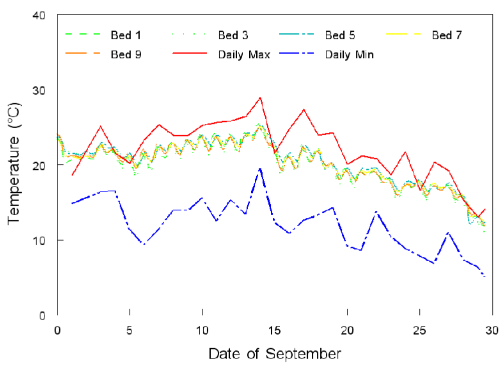

Figure 12. Medium temperatures and daily maximum and minimum ambient temperatures in the pot-in-pot plot across September of 2003.

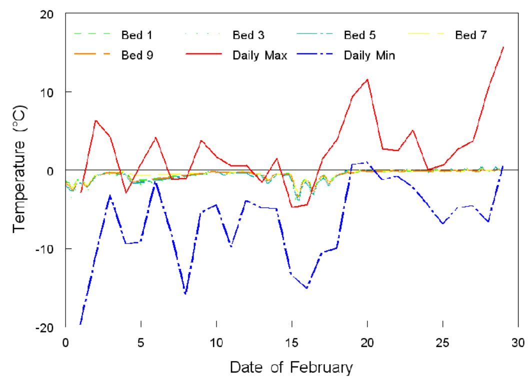

Figure 13. Medium temperatures and daily maximum and minimum ambient temperatures in the pot-in-pot plot across February of 2004.

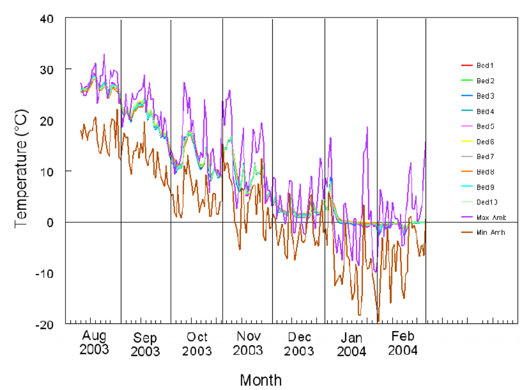

Figure 14. Average daily medium temperatures in 10 beds and daily minimum and maximum ambient temperatures in the pot-in-pot plot between August 6, 2003 and February 29, 2004.

Tree growth

Figure 15 shows the caliper of trees at 18 cm above the ground between July 3 and November 5, 2003. The trees had considerably higher growth rate in September than other months because of sufficient water application with a considerable portion of water loss through drainage. However, the growth rate among the 50 trees was not consistence.

Summary

Results from the first year study indicated that the amount of drainage water loss and nutrition leachate varied with irrigation rate and tree sizes. The system could be feasibly used to evaluate water and nutrition utilization efficiency, and tree growth response to changing weather conditions. The information on N, P, and K leachate detected with the system and drainage water pH might be useful to optimize nutrient application rate and schedule to produce health trees with less negative environmental impact. The system continuously monitored the medium temperature and moisture content during four seasons of a year, and provided a technical tool to evaluate the potentials of winter injury or summer heat damage to roots for the pot-in-pot nursery production.

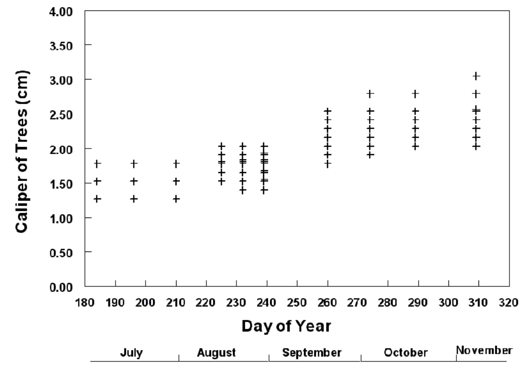

Figure 15. Caliper of trees at 18 cm above the ground between July 3 and November 5, 2003.

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